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Full Length Article

# Genetic mechanism of the granite buried-hill reservoir of the Penglai 9-1 oilfield in Bohai Sea

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ABSTRACT

The Penglai 9-1 oilfield is the largest granite buried-hill oilfield in China presently, genesis and evolution of the granite buried-hill reservoir is complex. Based on geochemical, geophysical, experimental simulation and other methods, and combined with field geological observation, genetic mechanism of the granite buried-hill reservoir of the Penglai 9-1 oilfield and its hydrocarbon accumulation mode were well investigated. Results showed that the granite was formed by magmatic intrusion along deep faults under intraplate breakup of North China Plate, it was the product of magmatic activities of Yanshan tectonic episode of Circum-Pacific Tectonic Region, and the intrusion time was 160–170 Ma of the Jurassic. Formation of the granite buried-hill reservoir was mainly controlled by the epigenic karstification and tectonic reconstruction, the Yanshanian weathering and denudation controlled macroscopic development characteristics of the granite buried-hill reservoir, and faults and joints formed by Cenozoic tectonic movement promoted modification of the granite buried-hill reservoir. Laterally, thickness of the granite buried-hill reservoir had a positive correlation with fracture density. Vertically, the granite rocks could be divided into five zones: soil zone, sandy zone, broken zone, fracture zone and base rock zone. The upper-middle part (sandy zone, broken zone, fracture zone) of the granite buried hill was the high-quality favorable reservoir zone and the main oil-bearing interval.



## 1. Introduction

The Penglai 9-1 oilfield is the largest Mesozoic granite buried-hill oilfield in China at present (Bai et al., 2015; Deng, 2015; Ye et al., 2016). The main productive layers of this oilfield are the Mesozoic granite buried hill, which formed complex hydrocarbon reservoirs with overlying Neogene Guantao Formation and Minghuazhen Formation. The proven geological reserve of the Mesozoic granite is about $0.18 \times 10^9$ t, which accounted for more than 80% of total reserve in this oilfield.

From the exploration processes of large igneous reservoirs in China and other countries, such igneous reservoirs have huge exploration potentials; the effective configuration between igneous reservoirs and source rocks can be favorable for formation of medium-large scale igneous reservoirs, such as the Lapaz oilfield in Venezuela, the Bach Ho oilfield in Vietnam, the Jatibarang oil and gas field in Indonesia, the Kudu gas field in Namibia, the Xushen gas field in the Songliao Basin and the Kelameili gas field in the Junggar Basin of China (Landes et al., 1960; P'an, 1982; Petford and McCaffrey, 2003; Xu et al., 2008; Zou et al., 2008; Cuong and Warren, 2009; Kuang et al., 2010; Dou et al., 2015). According to exploration practices in the Bohai Sea, the Mesozoic and Cenozoic igneous rocks are widely developed. Currently, oil and gas have been discovered in igneous rocks in Jinzhou 20-2 and Jinzhou 428 west oilfields, Bozhong 13-1 and Bozhong 34-9 structures (Qiao et al., 2002; Zhou et al., 2005; Gong, 2010). As a new type of oil and gas exploration domain, effectiveness of the igneous reservoirs was a key factor of hydrocarbon accumulation, but compared with conventional reservoirs, igneous rocks of different types have bigger difference and uncertainty (Vernik, 1990; Levin, 1995; Gu et al., 2002; Schutter, 2003; Sruoga and Rubinstein, 2007; Zhang et al., 2010). Hence, development and evolution, distribution scale as well as genetic mechanism of the igneous reservoirs usually influence exploration effectiveness of the igneous hydrocarbon reservoirs directly. Taking the Penglai 9-1 granite buried-hill oilfield as a case, and combined with tectonic environment, development features and distribution scale of the granite in the Bohai Sea, the genetic mechanism of the granite buried-hill reservoirs in the Penglai 9-1 oilfield were well analyzed, and then petroleum

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geological significance and exploration potential of the igneous rocks were discussed according to the exploration history and the latest drilling results in the Bohai Sea.

## 2. Geological background

### 2.1. Current tentonic characteristics

The Penglai 9-1 oilfield is located in the Miaoxibei uplift with a NE direction in the eastern Bohai Sea, it is near the Penglai 15-2 oilfield on the south. The east side of the Penglai 9-1 oilfield is adjacent to the Miaoxibei sub-sag, and the boundary is the Miaoxi 1 fault; the west side of the Penglai 9-1 oilfield which is the slope belt transits toward the Bodong sag; the Penglai 9-1 structure is generally a monocline which gradually is uplifted from west to east. On the NE profile, the Penglai 9-1 structure is separated by the NW-direction Miaobei 1 fault and Miaobei 2 fault, and show apparent sectional feature, i.e., its south and north parts are independent tectonic highs, and its central part is a broad and gentle saddle (Fig. 1). The Mesozoic buried hill is directly overlaid by the Neogene Guantao Formation and Minghuazhen Formation as well as Quaternary Pingyuan Formation; the Neogene contact with the underlying buried hill in the angular unconformity pattern. According to stratigraphic features of the buried hill revealed by drilled wells, the lithology of the south and north hills (Well block 3, Well block 6 and Well block 9) is the Archaean-Proterozoic metamorphic rocks which are dominated by quartz schist and mica schist, and the lithology of the saddle is Mesozoic acid irruptive rocks which are dominated by monzonitic granite and granodiorite.

### 2.2. Tectonic setting of granite intrusion

The Bohai Bay Basin is a Mesozoic-Cenozoic continental rift basin which developed under the North China Craton Basin background. The Bohai Bay Basin joins with the Siberian plate by the Xingmeng orogenic zone in the north, the Yangtze plate by the Qinling-Dabie obduction zone in the south; it extend to the Taihang Mountains and the near EW-trending Yanshan folded belt in the west, and to two positive tectonic units (Luxi uplift and Jiaoliao uplift) in the east (Fig. 2).

Since the Paleozoic, the Bohai Bay Basin experienced multiple tectonic movements (such as Caledonian movement, Hercynian movement, Indosinian movement, Yanshan movement and Himalayan movement), leading to superimposition, conversion and reconstruction of different tectonic regimes, and transition of the Bohai Bay Basin from the stable cratonic basin to the unstable intra-continental rift basin (Zhu et al., 2009; Xia et al., 2012; Zhou et al., 2015). The collision and breakup of plates usually accompany with violent volcanic activity. The North China Plate underwent a strong breakup since Mesozoic, thus continuous rifting of the North China Plate provided a favorable condition for extensive development of igneous rocks in the Bohai Sea. Since the Mesozoic, under influence of closure of the Paleo-Asian Ocean and continuous subduction of the Pacific Ocean Plate in the south, multiple violent tectonic magma activities are developed. Major regions of igneous rocks in the Bohai Sea include the Early Mesozoic igneous rocks in the Paleo-Asian Ocean tectonic domain, the Middle-Late Mesozoic igneous rocks and the Cenozoic igneous rocks in the Circum-Pacific Tectonic Region. Since the Mesozoic, due to plate collision and subduction, occurrence of intra-continental breakup of the North China Plate is a fundamental reason for extensive development of Mesozoic and Cenozoic igneous rocks in the Bohai Sea (Fig. 3). The forming background of the Mesozoic granite in the Penglai 9-1 oilfield coincides with intra-plate breakup under continuous subduction of the Pacific Ocean Plate during the Middle Jurassic, therefore, the Mesozoic granite in the Penglai 9-1 oilfield belongs to the Middle-Late Mesozoic igneous rock of the Circum-Pacific Tectonic Region.

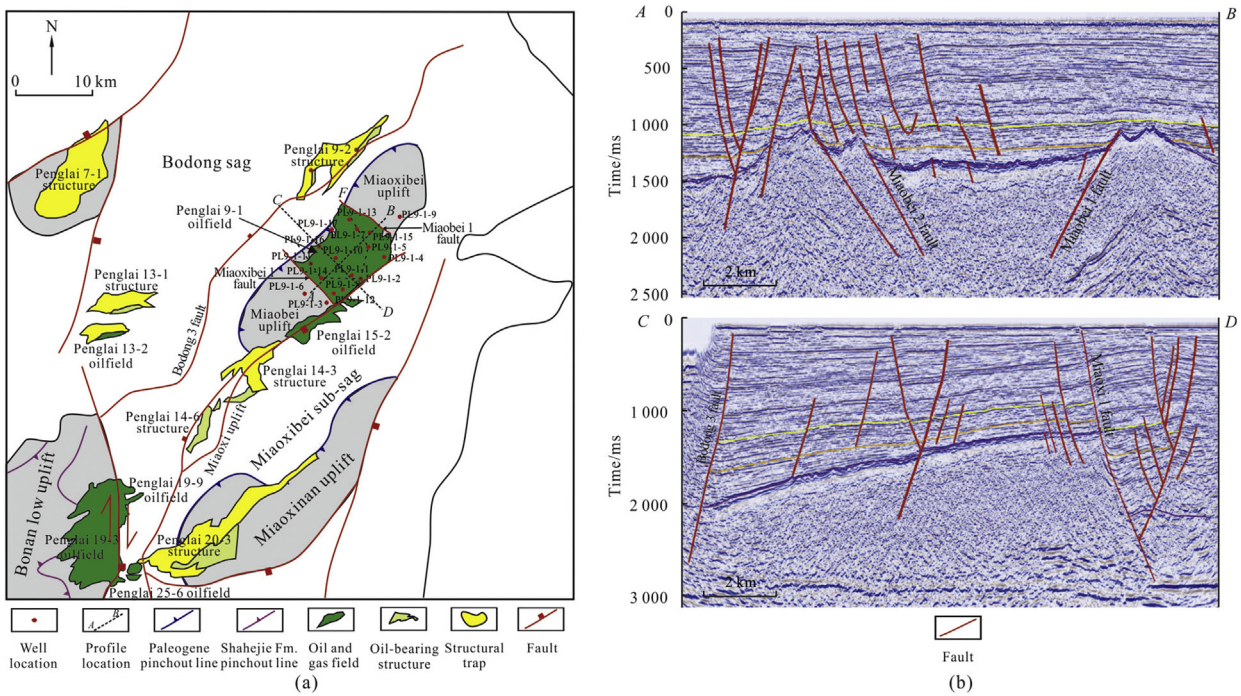


**Fig. 1.** Regional tectonic characteristics of the Penglai 9-1 oilfield. (a) Tectonic division of the Penglai 9-1 oilfield and its peripheral region showing that the Penglai 9-1 oilfield is located in the Miaoxibei uplift; (b) characteristics of seismic profiles of the Penglai 9-1 oilfield showing that the Penglai 9-1 structure is a monocline which gradually is uplifted from west to east, it is separated by Miaobei 1 fault and Miaobei 2 fault in the north-east direction, and has independent tectonic highs in the south and north parts as well as the broad-gentle saddle in the central part.

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